Stellar Structure and Evolution 2020

Computer Lab - Assignment

1. Introduction

The goal of this assignment is to study the evolution of a 2 Msun star and compare its evolution with that of the Sun. The star has a solar composition and the analysis has to be made from pre-main sequence to the end of the stellar life. This study will be performed via a numerical simulation using the module MESA Star of the code MESA[1].

MESA is a suite of libraries for a wide range of applications in computational stellar astrophysics. It contains a 1D stellar evolution module, MESA Star, which combines many of the numerical and physical modules for simulations of a wide range of stellar evolution scenarios ranging from very low-mass stars to massive stars, including advanced evolutionary phases. MESA Star solves the fully coupled structure and composition equations simultaneously. More information on MESA and MESA Star can be found at http://mesa.sourceforge.net/.

2. Setting up MESA Star

In order to avoid the time-consuming installation of MESA on an individual basis, you will make use of a single source code directory. The location of the code is indicated by setting the environment variables MESASDK_ROOT and MESA_DIR. To set these variables, open the file ~/.cshrc

```
gedit ~/.cshrc &
```

Then, add at the end the lines

```
setenv MESASDK_ROOT /disks/web1/users/nielsen/mesasdk
setenv MESA_DIR /disks/web1/users/nielsen/mesa-r7624
```

and save the file. Finally, update the environment variables.

```
source ~/.cshrc
```

You should now be able to use MESA.

The $MESA_DIR/star/work folder contains an example to check that the Mesa Star module runs. Create a working directory and make a copy of this folder. The working directory must be located in one of the data disks on your office computer, such as /net/computer_name/data1, or on a public data disk (in /disks). It should not be created in /home/username

```
mkdir /your_location/your_working_directory
cd /your_location/your_working_directory/
cp -rf $MESA_DIR/star/work .
```

Then, enter the work directory and compile the code.

```
cd work
source $MESASDK_ROOT/bin/mesasdk_init.csh
./mk
```

[1] MESA stands for Modules for Experiments in Stellar Astrophysics.

To recompile the code, you need to repeat the last two lines. Finally, run the code.
./rn
It should run for a few minutes while displaying various pieces of information on the evolution of the star. If this is the case, you can move on to the next section.

3. Running MESA Star

Now that Mesa Star is set up, you will run the simulation corresponding to the assignment.
The output files that you need to complete the assignment are in the LOGS folder. They consist of a collection of files profile#.data. Each of these files contains information on the star at a given time.
In the file, the zones are ordered from the surface to the core, zone 1 corresponding to the surface and the last zone corresponding to the core.

An example of the instructions provided to Mesa Star to run the simulation are contained in the file inlist_2M_prems_to_wd. This file contains numerous parameters which should be varied according to what you want to model.

4. The Assignment

The assignment for this computer lab is composed of running the MESA code twice. The first time is to compute the evolution of a 2Msun star and the second one is to compute the evolution of a 1Msun star. You will have to make four plots using the output files of those runs and write an essay where you clearly explain the evolution of the 2Msun star and make comments to compare such evolution with that of the 1MSun star. You do not need to explain the evolution of the Sun separately. The plots and the essay can be produced with any program you want.
You need to create four plots to analyse the stellar evolution. The plots and instructions are the following:

a) Evolution of the core in the log Tc − logρc plane

- Using the output files created during the simulation, plot the evolution of the core in the log Tc − log ρc plane where Tc and ρc are the temperature and density of the core respectively. Use log Tc as the horizontal axis and logρc as the vertical axis.
- Label the evolutionary stages.
- Indicate the age of the star at different places.
- Indicate the regions of the log Tc − log ρc plane corresponding to the four different equations of states. Derive the equations delimiting these different zones.
- Add the theoretical evolutionary track of a 2Msun and of a 1Msun star in the log Tc − logρc plane.
- Mark the current position of the solar core.

b) Hertzsprung-Russell diagram

- Using the output files created during the simulation, plot the evolution of the stars in the Hertzsprung-Russell diagram.
- Label the evolutionary stages.
- Indicate the age of the stars at different places.

c) Convection in the pre-main sequence phase

- Plot the adiabatic and radiative gradients as a function of radius when the stars are in the pre-main sequence phase. You only need to make use of a single profile#.data file. However, this file has to correspond to the pre-main sequence phase.
- Label the regions where convection occurs.

d) Convection in the main sequence phase

- Plot the adiabatic and radiative gradients as a function of radius when the stars are in the main sequence phase. You only need to make use of a single profile#.data file. However, this file has to correspond to the main sequence phase.
- Label the regions where convection occurs.

Finally, you need to write an essay about the evolution of the 2Msun star and make sure to compare it with that of the Sun. The essay must be written according to the following structure:

1. Introduction
2. Methods: This section must only contain one paragraph. A precise description of the code is not required.
3. Results: In this section, you must present the four plots and describe them without interpretation.
4. Discussion: This section must contain one subsection for each evolutionary stage of the 2Msun star. In each subsection, you must explain physically and in detail the evolution of the star based on the four plots. Make sure to estate the differences and similarities between the evolution of the 2Msun and that of the Sun for each stage.
5. Conclusion

The lectures and the reading materials must be enough for you to complete this assignment successfully. However, you can use other sources if you want. If you do, cite these sources in an appropriate manner. The essay should not exceed 6 pages of A4 size, including figures. The figures should not be larger than half of an A4 and the 6 pages are to be counted in Times New Roman font of size 12. Please do indicate your student number(s) on the assignment.

5. Important Information

The deadline to hand in the essay is May 29th, 2020 at noon.

Please upload the pdf with your essay via blackboard.

The essay will be graded and it represents the 33% of the your final grade. The grades for the assignment will be given on June 12, 2020.